Predictors of delirium after cardiac surgery delirium: Effect of beating-heart (off-pump) surgery

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See related editorial on page 7.

Background: Despite improved outcomes after cardiac operations, postoperative delirium remains a common complication that is associated with increased morbidity and prolonged hospital stay.

Methods: Univariate and multivariate predictors of postoperative delirium were determined from prospectively gathered data on 16,184 patients undergoing cardiac operations with cardiopulmonary bypass (conventional, n = 14,342) and without cardiopulmonary bypass (beating-heart surgery, n = 1847) between April 1996 and August 2001. Delirium was defined as a transient mental syndrome of acute onset characterized by global impairment of cognitive functions, a reduced level of consciousness, attentional abnormalities, increased or decreased psychomotor activity, and a disordered sleep-wake cycle.

Results: The overall prevalence of postoperative delirium was 8.4%. Of 49 selected patient-related risk factors and treatment variables, 35 were highly associated with postoperative delirium by univariate analysis. Stepwise logistic regression revealed the following variables as independent predictors of delirium: history of cerebrovascular disease, peripheral vascular disease, atrial fibrillation, diabetes mellitus, left ventricular ejection fraction of 30% or less, preoperative cardiogenic shock, urgent operation, intraoperative hemofiltration, operation time of 3 hours or more, and a high perioperative transfusion requirement. Two variables were identified as having a significant protective effect against postoperative delirium: beating-heart surgery and younger patient age.

Conclusions: Postoperative delirium is a common complication in cardiac operations. The increased use of beating-heart surgery without cardiopulmonary bypass may lead to a lower prevalence of this complication and thus improve patient outcomes.

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The number of cardiac operations is steadily increasing in industrialized countries. At the same time, the proportion of patients with elderly age and other risk factors for neurologic complications is also increasing.[1] Neurologic complications after cardiac operations, including delirium, are associated with increased morbidity and mortality, as well as prolonged hospital stays.[2]

Neuropsychological and psychiatric disorders after cardiac operations have been well described since the 1950s and continue to be a subject of active research.[3] In contrast to relatively uncommon major neurologic complications, such as stroke, neuropsychological impairment is a common problem after cardiac operations; most

studies report a prevalence of approximately 30%.[2,4,5,6] However, the etiology and pathogenesis of cognitive impairment and delirium remain unknown. Many preoperative, intraoperative, and postoperative variables have been described as risk factors for these complications, but their exact etiologic roles have yet to be determined.

Many investigators have focused on the deleterious effects of cardiopulmonary bypass (CPB) on postoperative cognitive function. A recent development in cardiac surgery is the ability to perform operations, particularly coronary bypass surgery, without the use of CPB (so-called beating-heart [BH] surgery). Several studies have compared postoperative cognitive outcomes in patients undergoing BH surgery with those in patients undergoing conventional procedures with CPB, but results have been inconclusive.[7-13] Differences in the definition of neuropsychological impairment between studies may explain some of the discrepant results.[14]

The purpose of this study was to identify risk factors for post–cardiac surgery delirium in a large number of patients from a single institution. In addition, we attempted to evaluate the effect of BH surgery without CPB on postoperative delirium.

Methods

Study Population

A total of 16,184 consecutive adult patients underwent heart operations between April 1996 and August 2001 at the Leipzig Heart Center. To assess the effects of CPB on postoperative delirium, patients were divided into groups on the basis of the type of operation performed. Coronary artery bypass grafting (CABG) with CPB was performed in 8917 patients (CABG-CPB). For the purposes of this study, patients undergoing coronary bypass grafting with CPB support, but without cardioplegic arrest, were still considered part of the CABG-CPB group. CABG without CPB (BH), either through a median sternotomy (n = 765) or through a left lateral minithoracotomy (n = 1077), was performed in 1842 patients. Although most of these BH procedures were performed by 4 of our surgeons, all surgeons performed at least some of these operations. A third group of patients consisted of those undergoing cardiac valvular operations or combined CABG plus valvular operations (n = 5425). Patients undergoing replacement of the ascending aorta (n = 255) were also included in this group. All operations for this third group of patients were performed by using CPB and involved the opening of cardiac chambers (VALVE-CPB).

CPB was performed according to a standard protocol. The systemic body temperature was cooled to 32°C, mean arterial pressure was kept >60 mm Hg, and blood flow was maintained at 2.4 $L \cdot min^{-1} \cdot m^{-2}$ body surface area during CPB. Proximal coronary bypass anastomoses were performed with a single aortic crossclamp technique (since 1999) in the CABG-CPB group and with a side-clamp technique in the BH group. Cardiotomy suction and administration of aprotinin were routinely used in all patients. We did not use coated oxygenators or tubing.

Definition of Postoperative Delirium

In accordance with the American Psychiatric Association guidelines, postoperative delirium was defined as a transient mental syndrome of acute onset characterized by global impairment of cognitive functions, a reduced level of consciousness, attentional abnormalities, increased or decreased psychomotor activity, and a disordered sleep-wake cycle.[15,16] The diagnosis of delirium was made by physicians involved in the daily clinical care of patients and was most frequently made while patients were in the intensive care unit. Patients with prolonged delirium or focal neurologic signs underwent computed tomography of the brain to look for evidence of stroke.[17] Stroke patients with delirium were included in the study cohort.

Data Collection

Perioperative data were recorded prospectively by using an online database system as previously described (Medwork database software; Lenz + Partner GmbH, Dortmund, Germany).[18] All variables analyzed were entered by clinicians in a prospective fashion to accomplish a complete data set for each patient. Data quality was routinely assessed and verified by the generation of text documents that became the patient's chart during the hospital stay. Preoperative and intraoperative variables that were assessed as possible predictors of delirium are listed in Appendix 1. Postoperative variables were not analyzed as possible risk factors of delirium.

Statistical Analysis

Continuous variables are expressed as mean ± SD, and categorical data are expressed as proportions throughout the article. Comparisons of continuous variables between patients with and without postoperative delirium were performed with the Student unpaired *t* test or analysis of variance, with the appropriate correction for multiple comparisons. Categorical variables were compared by χ^2 analysis. Univariate analyses of risk factors for delirium were performed by calculating odds ratios (OR) with 95% confidence intervals. All *P* values were 2 tailed. Variables with a *P* value < .05 were subjected to a multivariate logistic regression model to determine the risk-adjusted predictors of delirium by using a backward (Wald) stepwise procedure. A *P* value of <.05 was used to enter and eliminate variables.[19] All statistical analyses were performed with the SPSS statistical package version 9.0 (SPSS Inc, Chicago, Ill).

Results

Baseline preoperative patient characteristics for the different surgical groups are shown in Table 1. Patients older than 70 years constituted 32.5% of the population, and 3.6% were 80 years of age or older. Most patients were male, and 3.6% of the study population had a history of cerebrovascular disease.

Patients in the CABG-CPB group had a significantly higher age compared with both the BH and the VALVE-CPB groups ($P < .0001$), and VALVE-CPB patients were significantly older than BH patients ($P < .0001$). The preoperative left ventricular ejection fraction was lowest in the VALVE-CPB group ($P < .0001$ compared with the other 2

TABLE 1. Preoperative patient characteristics for the different surgical groups

Variable	No.	Age (y)	Sex, Male (%)	LVEF (%)	CCS ≥3	NYHA ≥III	No. of grafts*
Total	16,184	64.8 ± 10.4	11,522 (71.2%)	52.0 ± 22.0	32.9%	77.7%	1.8 ± 1.2
CABG-CPB	8917	65.4 ± 9.2	6887 (77.2%)	53.0 ± 20.6	36.0%	79.9%	2.5 ± 0.8
BH	1842	63.1 ± 10.6	1402 (76.1%)	55.9 ± 20.7	39.6%	71.4%	1.3 ± 0.6
VALVE-CPB	5425	64.6 ± 12.0	3233 (59.6%)	48.9 ± 24.2	25.5%	76.2%	0.8 ± 1.2†

Continuous variables are expressed as mean ± SD.

CABG-CPB, Coronary artery bypass grafting with cardiopulmonary bypass; *BH,* beating heart surgery; *VALVE-CPB,* valvular surgery with cardiopulmonary bypass with or without coronary artery bypass grafting; *LVEF,* left ventricular ejection fraction; *NYHA,* New York Heart Association heart failure classification; *CCS,* Canadian Cardiovascular Society angina classification.

*Coronary artery bypass grafts.

†Combined coronary bypass plus valvular or ascending aortic surgery.

groups). The left ventricular ejection fraction in the BH group was significantly higher than in the CABG-CPB group ($P < .0001$). There were significantly more men in both coronary artery bypass groups compared with the VALVE-CPB group ($P < .0001$).

Patients in the CABG-CPB group had a higher prevalence of Canadian Cardiovascular Society classification 3 or greater and received more coronary bypass grafts than patients in the BH group ($P < .0001$ and $P = .01$, respectively). The prevalence of New York Heart Association (NYHA) class III or greater symptomatology was highest in the CABG-CPB group ($P < .0001$ compared with the other groups) and was higher in the VALVE-CPB group than in the BH group ($P < .0001$; Table 1).

The overall prevalence of postoperative delirium was 8.4% (n = 1354). Of these patients, 219 (16.2%) also had a diagnosis of perioperative stroke. The prevalence of delirium varied among the 3 surgical groups as shown in Figure 1. Postoperative delirium was significantly ($P < .0001$) less likely to occur in BH patients compared with the other 2 surgical groups. The prevalence of postoperative delirium in all patients ≥70 years of age was 12.9%, with significant differences among the 3 surgical groups (CABG-CPB, 11.9%; BH, 5.1%; VALVE-CPB, 16.4%; $P < .001$).

Patients with postoperative delirium were more prone to have postoperative respiratory insufficiency (32.9% vs 7.0%; $P < .0001$) and to require tracheal reintubation (23.5% vs 5.1%; $P < .0001$) than patients without delirium. In addition, patients with delirium had a significantly higher prevalence of sternum instability (7.5% vs 1.9%; $P < .0001$) and were more likely to require surgical revision of the sternal wound (6.4% vs 1.4%; $P < .0001$). Patients with delirium had a significantly longer intensive care stay (11.4 ± 12.3 days vs 3.5 ± 5.8 days; $P < .0001$), which we defined as the length of time spent in the intensive care unit (with mechanical ventilation) plus the intermediate care unit (without mechanical ventilation). Furthermore, total postoperative hospitalization in patients with delirium was significantly longer compared with patients without delirium (19.2 ± 16.1 days vs 11.0 ± 8.3 days; $P < .0001$).

Univariate analysis revealed that 35 of 49 recorded preoperative and intraoperative variables had a significant association with postoperative delirium (Appendix 1, bold). Significant variables were consecutively subjected to a stepwise logistic regression analysis. Ten variables were identified as independent predictors of postoperative delirium, and 2 variables were associated with a significantly lower prevalence of delirium (Table 2). Of particular note was that operation without CPB had a protective effect against delirium in this risk-adjusted analysis. The prevalence of perioperative independent predictors of delirium and statistically significant differences regarding these predictors among the 3 groups are shown in Table 3.

Discussion

This series was composed of more than 16,000 adults undergoing cardiac surgery, of whom 8.4% experienced postoperative delirium. All of the data were gathered in a prospective fashion by using an institutional software program that becomes the patient's medical chart while he or she is in the hospital.

The diagnosis of delirium is currently made with clinical assessment,[15,16] in contrast to postoperative neuropsychological impairment, which is diagnosed with neuropsychological tests and usually is part of a research protocol.[4,14,20] The definition of delirium chosen in this series is the same as that recommended by the American Psychiatric Association and is readily applicable by clinicians involved in the daily postoperative care of cardiac surgery patients. The symptoms of delirium—in particular, confusion—make neuropsychological testing impractical in this patient population. Postoperative delirium may represent a more severe form of neurologic injury than neuropsychological impairment, a complication that is known to be very common after cardiac surgery.[4,7,14,20]

The prevalence of postoperative delirium in our study varied among the different surgical procedures. Patients undergoing valve or combined valve and CABG operations had postoperative delirium more often than patients undergoing isolated CABG operations, a finding that has been

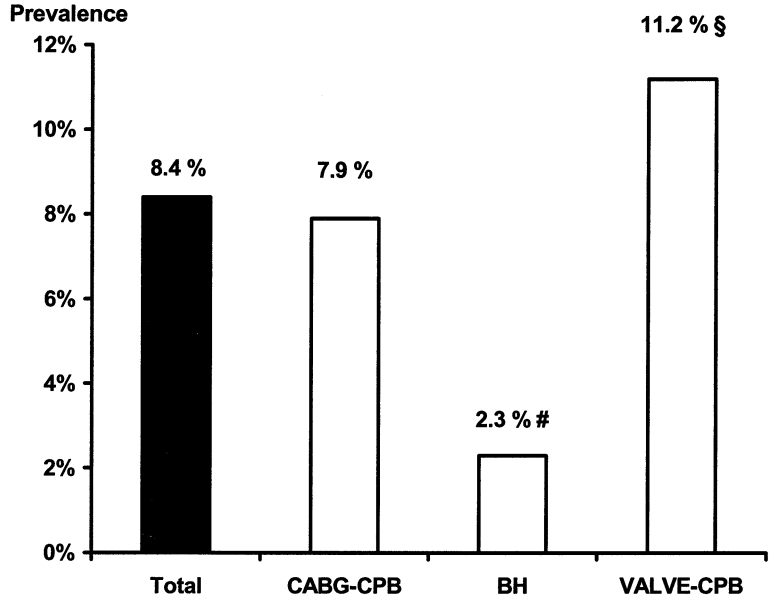

Figure 1. Prevalence of postoperative delirium according to the type of cardiac surgical procedure. *CABG-CPB,* Coronary artery bypass grafting with cardiopulmonary bypass; *BH,* beating heart surgery; *VALVE-CPB,* valvular surgery with or without coronary artery bypass grafting with cardiopulmonary bypass. #$P < .0001$ versus CABG-CPB and VALVE-CPB. §$P < .0001$ versus CABG-CPB.

TABLE 2. Independent predictors of postoperative delirium analyzed by multivariate logistic regression analysis

Variable	Odds ratio	95% Confidence interval	*P* value
Variables associated with higher risk of delirium			
History of cerebrovascular disease	2.15	1.69–2.72	<.0001
Atrial fibrillation	1.36	1.14–1.62	.0005
Diabetes mellitus	1.31	1.16–1.49	<.0001
Peripheral vascular disease	1.34	1.17–1.53	<.0001
LVEF ≤30%	1.30	1.09–1.49	.0041
Preoperative cardiogenic shock	1.23	1.05–1.45	.0122
Urgent operation	1.17	1.02–1.34	.0245
Operating time ≥3 h	1.26	1.01–1.45	.0009
Intraoperative hemofiltration	1.26	1.06–1.49	.0079
RBC transfusion ≥2000 mL	3.15	2.71–3.65	<.0001
Variables associated with lower risk of delirium			
Beating-heart surgery	0.47	0.32–0.69	.0001
Younger patient age			
Age <50 y	0.22	0.15–0.31	<.0001
Age ≥50 and <60 y	0.34	0.27–0.43	<.0001
Age ≥60 and <70 y	0.6	0.52–0.68	<.0001

LVEF, Left ventricular ejection fraction; *RBC,* red blood cells.

previously described.[21] The reason for this observation is unknown but may be related to embolization of air that is trapped within cardiac chambers during VALVE procedures.[22]

The cause of post–cardiac surgery delirium is unknown and is probably multifactorial in origin.[15] Most patients with delirium have this complication shortly after awakening from anesthesia,[23,24] and this suggests that intraoperative factors play a major role in the pathogenesis. It is for this reason that we did not include postoperative variables in our analysis of predictors of delirium.

A history of cerebrovascular disease was one of the strongest predictors of delirium in this series, with an OR of 2.15. The increased risk may be explained by the existence of atherosclerosis within the cerebrovascular system, particularly of the carotid arteries.[4,25] Generalized atherosclerosis increases the risk of cerebral embolization, particularly during intraoperative aortic manipulation.[26] The finding of diabetes (OR, 1.30) and peripheral vascular disease (OR, 1.34) as independent predictors of delirium may also be a result of their close association with atherosclerotic disease burden.

Previous investigators have observed an association between severity of underlying cardiac disease and postoperative delirium. Heller and associates[27] described an increasing prevalence of postoperative delirium with increasing NYHA heart failure classification. Similarly, we found impaired left ventricular ejection fraction (OR, 1.23) and preoperative cardiogenic shock (OR, 1.24) to be independent predictors of delirium. Urgent surgery was also a predictor of delirium (OR, 1.16); this risk factor is a marker of the severity of underlying cardiac pathology.

Preoperative history of atrial fibrillation was an independent predictor of postoperative delirium (OR, 1.35) in this study, possibly because of its widely recognized association with thromboembolization. Several previous investigators have described an association between cerebral embolization during cardiac operations and postoperative neurobehavioral deficits.[20,26,28-30]

Prolonged duration of surgery (OR, 1.29) and intraoperative hemofiltration (OR, 1.24) are indicators of increased operative complexity, a factor that has been previously shown to influence postoperative neurologic outcomes.[5] In addition, prolonged operations involve longer CPB times, another risk factor for neurologic complications.[2,25,31] The effect of prolonged anesthetic time on postoperative delirium is controversial; some investigators report a significant association, and others describe no correlation.[32] It is interesting to note that a similar proportion of CABG-CPB and BH patients had a prolonged surgical procedure (Table 3), yet the prevalence of delirium was significantly lower in the BH group. Part of this difference may be related to the avoidance of CPB in the BH group.

A high transfusion requirement was a strong predictor of postoperative delirium (OR, 3.12). However, our database is unable to distinguish between intraoperative and postoperative transfusion administration. Increased transfusion requirement may have therefore partially reflected postoperative complications, making interpretation of this predictor difficult.

Advanced age is one of the most commonly reported independent predictors of postoperative delirium,[25,33,34] probably because of its close association with the atherosclerotic disease process. Approximately one third of our patient population was older than 70 years of age, and our data confirmed that such patients are at increased risk for delirium (Table 2; Appendix 1).

The beneficial effect of BH surgery (OR, 0.14) on the prevalence of postoperative delirium in this series may be due to avoiding the deleterious effects of CPB, as already stated. CPB may lead to a higher prevalence of postoperative delirium because of hypotensive periods during CPB and nonpulsatile blood flow.[35] In addition, the risk of gaseous and particulate cerebral embolization, a widely recognized problem during CPB, is avoided in BH surgery.[7,20,28-30] Furthermore, the lower prevalence of delirium in the BH group may be explained by the avoidance of ascending aortic cannulation and the subsequent risk of atherosclerotic embolization. Indeed, aortic manipulation is avoided altogether in those BH patients who undergo minimally invasive direct CABG (MIDCAB).

Preoperative patient characteristics in the BH group revealed a younger mean age and higher left ventricular ejection fraction than in the CABG-CPB group. Furthermore, the number of CABGs was significantly lower than in the CABG-CPB group. This finding was expected, however, given that the BH group was composed of patients who underwent both off-pump CABG for 1 or more bypass grafts and minimally invasive direct CABG for single bypass grafting (that is, left internal thoracic artery to the left anterior descending coronary artery). In addition, the prevalence of severe clinical symptoms (NYHA classification of III or higher and Canadian Cardiovascular Society classification ≥3) was significantly higher in the CABG-CPB group compared with the BH group.

This study has several limitations. Because of the retrospective design of our study and the lack of randomization, selection bias may have accounted for some of the observed differences in delirium among surgical groups. That is, lower-risk patients may have been selected to undergo BH surgery. The possibility of selection bias, as for all nonrandomized studies, is the main limitation of our study. However, it is important to note that the BH group did not have the lowest prevalence of

TABLE 3. Prevalence of independent predictors of postoperative delirium in relation to the different surgical procedures

	Prevalence (%)			
Variable	Total	CABG-CPB	BH	VALVE-CPB
Variables associated with higher risk of delirium*				
History of cerebrovascular disease	3.6	3.4	3.1	4.1
Atrial fibrillation	9.1	4.2	3.3	19.1†
Diabetes mellitus	36.8	41.2‡	29.4	27.8
Peripheral vascular disease	20.0	21.8‡	14.7§	18.8
LVEF ≤30%	9.2	8.3‖	6.1	11.7†
Preoperative cardiogenic shock	15.5	10.1	8.5	26.6†
Urgent operation	23.7	22.0¶	12.9	30.1†
Operating time ≥3 h	21.6	19.4	18.8	26.1†
Intraoperative hemofiltration	11.2	7.4	N/A	17.5#
RBC transfusion ≥2000 mL	10.3	8.8¶	4.1	14.9†
Variables associated with lower risk of delirium*				
Beating-heart surgery	11.4	0	100	0
Younger patient age				
Age <50 y	8.8	6.3‡	12.5	11.7
Age ≥50 and <60 y	16.6	17.1	20.6**	14.4†
Age ≥60 and <70 y	38.3	40.4§	37.9	34.9

CABG-CPB, Coronary artery bypass grafting with cardiopulmonary bypass; *BH,* beating heart surgery; *VALVE-CPB,* valvular surgery with cardiopulmonary bypass witih or without coronary artery bypass grafting; *LVEF,* left ventricular ejection fraction; *RBC,* red blood cells; *N/A,* not applicable.
*Analyzed by multivariate logistic regression analysis.
†$P < .0001$ vs CABG-CPB and BH.
‡$P < .0001$ vs BH and VALVE-CPB.
§$P < .0001$ vs VALVE-CPB.
‖$P = .001$ vs BH.
¶$P < .0001$ vs BH.
#$P < .0001$ vs CABG-CPB.
**$P = .002$ vs CABG-CPB.

all independent predictors of delirium (Table 3). In addition, multivariate logistic regression analysis revealed that BH surgery was associated with a lower risk of delirium, even after other risk factors were accounted for. We therefore believe that BH surgery, with subsequent avoidance of CPB and minimization of aortic manipulation, may lead to a lower risk of postoperative delirium. Recently published series comparing postoperative neurocognitive outcome in patients undergoing on- and off-pump coronary bypass operations have confirmed our findings of better results with off-pump CABG.[11-13]

Another limitation of this study is the fact that the clinicians who were responsible for making the diagnosis of delirium were not blinded to surgical group status. However, a very large number of clinicians were involved in the diagnosis of delirium, and most had no vested interest in the outcome of our study. Another limitation is that the large number of clinicians involved in our study increases the chance that the diagnosis of delirium was not always consistent from patient to patient. However, the large number of clinicians also increases the generalizability of our findings. Furthermore, independent neurologists were often consulted to confirm the diagnosis of delirium. We therefore believe that our results are relatively unbiased, generalizable, and valid.

Conclusions

Postoperative delirium is a common complication after cardiac surgical procedures. Since delirium and other neurologic complications are associated with increased morbidity and resource utilization, it is important to identify their independent predictors. BH surgery without CPB seems to be associated with a decreased risk of postoperative delirium and should be considered as one of the strategies for minimizing cerebral injury during cardiac operations.

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APPENDIX 1. Perioperative variables analyzed by univariate analysis: factors that had a statistically significant association with delirium are printed in bold

Variable	Prevalence, % (n) Patients with delirium (n = 1354)	Patients without delirium (n = 14,830)	*P* value
Preoperative variables			
Age			
Age < 50 years	2.7% (37)	9.4% (1392)	<.0001
Age ≥ 50 < 60 years	7.6% (103)	17.5% (2589)	<.0001
Age ≥ 60 < 70 years	33.9% (459)	38.7% (5746)	<.0001
Age ≥ 70 < 80 years	48.9% (663)	30.9% (4595)	<.0001
Age ≥ 80 years	6.8% (92)	3.4% (508)	<.0001
Sex (Male)	73.4% (994)	71.0% (10,528)	.06
History of syncope	12.3% (167)	9.7% (1444)	.002
History of embolism	4.7% (64)	3.1% (455)	.002
History of cardiogenic shock	21.0% (285)	10.9% (1622)	<.0001
Diabetes mellitus (glucose intolerance treated with diet, oral hypoglycemics, or insulin)	42.5% (576)	32.5% (4817)	<.0001
Hyperlipidemia	43.2% (585)	46.5% (6901)	.021
Arterial hypertension (patient taking antihypertensive medication before surgery)	70.7% (957)	67.5% (10,017)	.017
History of renal disease (history of renal failure or pathologic increased serum creatinine treated medically without hemofiltration and/or dialysis)	8.6% (117)	3.9% (588)	<.0001
Dialysis-dependent renal insufficiency	0.7% (10)	0.7% (103)	.864
Preoperative infection (infectious disease, including endocarditis)	3.6% (49)	1.9% (290)	<.0001
History of cerebrovascular disease (including stroke, TIA, and PRIND)	8.5% (115)	3.2% (474)	<.0001
NYHA ≥III	81.7% (1106)	77.3% (11,465)	<.0001
LVEF ≤30% (assessed by angiography or 2-dimensional echocardiography)	14.5% (196)	8.7% (1295)	<.0001
History of peripheral vascular disease	29.4% (398)	19.1% (2831)	<.0001
Atrial fibrillation (history of preoperative atrial fibrillation)	15.8% (214)	8.5% (1259)	<.0001
Urgent operation	35.0% (474)	22.6% (3358)	<.0001
History of pulmonary disease (chronic pathologic pulmonary function test)	9.2% (124)	6.7% (995)	.001
Prior myocardial infarction	43.3% (586)	42.4% (6290)	.565
Emergency surgery (emergency surgery due to complications during coronary angiography and/or PTCA)	0.9% (12)	0.6% (89)	.204
CCS ≥3	34.4% (466)	32.8% (4861)	.227
Prior cardiac surgery	6.3% (85)	5.3% (784)	.13
Prior CABG	3.8% (52)	3.3% (482)	.234
Prior surgery for aortic aneurysm	0.1% (2)	0.3% (50)	.319
Prior aortic valve surgery	0.7% (9)	1.0% (153)	.252
Prior mitral valve surgery	1.5% (20)	0.9% (144)	.087
Intraoperative variables			
Duration of surgery ≥3 h	29.3% (397)	20.9% (3094)	<.0001

Continued

APPENDIX 1. Continued

Variable	Prevalence, % (n) Patients with delirium (n = 1354)	Patients without delirium (n = 14,830)	*P* value
Total CPB time ≥2 h	21.9% (297)	12.6% (1875)	<.0001
Ischemic time ≥1 h	30.4% (411)	21.3% (3163)	<.0001
Intraoperative hemofiltration	16.9% (229)	9.5% (1409)	<.0001
Intraoperative hypothermia <32°C	46.9% (635)	36.4% (5405)	<.0001
Intraoperative RBC transfusion ≥1000 mL	6.1% (83)	2.5% (377)	<.0001
Intraoperative low cardiac output	3.6% (49)	2.1% (3011)	.001
Intraoperative IABP	3.0% (41)	1.9% (280)	.006
Intraoperative need for pacemaker stimulation	28.9% (392)	20.0% (2972)	<.0001
Use of cardioplegia	81.5% (1103)	77.1% (11,435)	<.0001
BH	3.2% (43)	12.1% (1799)	<.0001
OPCAB	2.4% (32)	4.9% (733)	<.0001
MIDCAB	0.8% (11)	7.2% (1066)	<.0001
CABG-CPB	52.4% (706)	57.1% (8211)	.024
VALVE-CPB	44.7% (605)	32.5% (4820)	<.0001
Valve surgery	44.6% (604)	32.5% (4821)	<.0001
Combined surgery (CABG and valvular surgery, ascending aortic surgery, and/or other procedures)	25% (338)	14.6% (2168)	<.0001
Double valve surgery	3.9% (53)	2.2% (328)	<.0001
OPCAB—conversion to CABG with cardiopulmonary bypass	0.07% (1)	0.2% (30)	.513
Aortic valve and/or ascending aortic surgery	12.0% (163)	11.2% (1667)	.37
Mitral valve surgery	3.8% (51)	4.4% (657)	.714
Intraoperative blood loss ≥500 mL	1.0% (14)	0.6% (88)	.069
Perioperative variables			
Perioperative RBC transfusion ≥2000 mL	30.4% (411)	8.5% (1254)	<.0001

CABG-CPB, Coronary artery bypass grafting with cardiopulmonary bypass; *BH,* beating heart surgery; *VALVE-CPB,* valvular with cardiopulmonary bypass with or without coronary artery bypass grafting; *CABG,* coronary artery bypass grafting; *OPCAB,* off-pump coronary artery bypass grafting; *MIDCAB,* minimally invasive direct coronary artery bypass grafting; *RBC,* red blood cells; *LVEF,* left ventricular ejection fraction; *PTCA,* percutaneous transcoronary angioplasty; *CPB,* cardiopulmonary bypass; *IABP,* intra-aortic balloon pump; *TIA,* transient ischemic attack; *PRIND,* prolonged reversible ischemic neurologic deficit; *NYHA,* New York Heart Association heart failure classification; *CCS,* Canadian Cardiovascular Society angina classification.